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RESULTS OF TANK TESTING TO EVALUATE THE EFFECT OF COPPER, NICKEL, SILICON AND MANGANESE IN WELD METAL ON SEA WATER CORROSION RESISTANCE

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REPORT MTL 89-65(TR)

RESULTS OF TANK TESTING TO EVALUATE THE EFFECT OF COPPER, NICKEL, SILICON AND MANGANESE IN WELD METAL ON SEA WATER CORROSION RESISTANCE

by

R.J. Brigham and V. Mitrovic-Scepanovic

ABSTRACT

Five submerged-arc weldments containing Mn and Si in the range 0.13 to 0.46% and four shielded-metal-arc weldments with controlled additions of Si, Cu and Ni were tested in the CANMET tank test. Si and Mn were found to be detrimental to weld metal corrosion resistance whereas Cu and Ni, either singly or in combination, were beneficial.

LABORATOIRES DE LA TECHNOLOGIE DES MÉTAUX
RAPPORT: MTL 89-65(TR)

RÉSULTATS DES TESTS DE RÉSERVOIR POUR ÉVALUER L'ÉFFET DE CUIVRE, NICKEL, SILICIUM ET MANGANESE DANS LE MÉTAL DE SOUDURE FACE A LA CORROSION DANS L'EAU DE MER

par

R.J. Brigham and V. Mitrovic-Scepanovic

RESUME

Cinq soudures à l'arc sous flux avec Mn et Si dans la plage 0.13 à 0.46% et quatre soudures à l'arc avec électrode fusible en atmosphère protectrice avec additions controllée de Si, Cu et Ni ont étées mises à l'épreuve dans le test de réservoir à CANMET. Le taux de corrosion du métal de soudure a augmenté avec l'addition du Si et Mn mais a diminué à cause de Cu et Ni, soit seul ou en combinaison.

INTRODUCTION

Under contract to the Canadian Coast Guard (Fleet Systems), Malik et al. (1) prepared nine trapezoidal plates containing submerged-arc and shielded-metal-arc welds for testing in the CANMET tank test. The welding consumables fell into the following groups based on welding technique and composition:

Group 1 - Specimens 302M and 302N
SMAW consumables consisting of CLA48018-RCR with low Si (0.13%, 302M) and high Si (0.38%, 302N) for direct comparison of the effect of Si on the corrosion behaviour of Cu/Ni electrodes.

Group 2 - Specimens 302P, 302Q and 302S
SAW consumables containing low Mn (~1.2%) with increasing amounts of alloyed Si.

Group 3 - Specimens 302T and 302U
SAW consumables containing high Mn (~1.5%) with two levels of Si for comparison with the alloys in Group 2.

Group 4 - Specimens 302X and AM24 (designated W in the Fleet Report)
SMAW consumables with optimum levels of Cu (AM24) and Ni (302X) as determined by Malik et al(1).

The compositions of the weld metals and base plate reproduced from the Materials Technology Centre report (1) are given in Table 1. Microstructural analysis, mechanical properties and corrosion rates determined by anodic dissolution tests were also determined by Malik et al. Their anodic dissolution results are given in Table 2.

EXPERIMENTAL

The nine trapezoidal specimens containing weldments were subjected to the standard CANMET tank test (2,3) for 6 months in 3.5% NaCl solution held at approximately 1 to 2°C. The samples were taken out of the tank at two-month intervals; the corrosion products were removed by wire brushing; and the depth of attack of the weld metal and heat-affected zones were measured using a profilometer. In addition, a micrometer was used to confirm the depth of attack at selected points over the whole surface after 6 months of exposure. The maximum depth of attack measured from the original surface was used as a criterion for the degree of corrosion.

RESULTS AND DISCUSSION

Photographs of the corroded samples are shown in Fig. 1 to 9, and the maximum depths of attack of the weld metal are listed in Table 2 where they can be compared with the anodic dissolution results given both as maximum and average depth of attack. The pitting morphology which is evident on the tank test specimens, Fig. 1 to 9, makes a quantitative analysis of the extent of attack difficult. But using anodic dissolution and tank test results listed in Table 2 in conjunction with visual observations of the corroded tank-test specimens, Fig. 1 to 9, it is possible to evaluate, at least qualitatively, the effects of alloyed Si, Mn, Cu and Ni on weld-metal corrosion. More detailed quantitative analysis will be carried out when surface profiling and analysis is done with the laser scanner on order at CANMET. Qualitatively, the following observations pertain:

Group 1 - It is clear that 302M(48018-RCR, low Si) is more resistant to attack than 302N(48018-RCR, high Si). This result confirms earlier observations (2,3) that Si, below a certain concentration, produces a significant improvement in corrosion resistance. Consequently, high Si RCR can be expected to produce results similar to ESAB 73.08, as the composition would suggest, while low Si RCR is much more corrosion resistant, and indeed, as seen in earlier work (3), is approximately equivalent to E55018-C1. It should be noted that 302N is an excellent match with the base plate while 302M, being more resistant, promotes HAZ attack - particularly at the last pass. The improved corrosion resistance of the low Si weld metal (M) is obtained at the expense of user appeal as shown in Fig. 1 where the roughness of the beads indicates a serious lack of fluidity during deposition.

Group 2 - The weldments in Specimens 302P, Q and S containing ~1.2% and with 0.13, 0.24 and 0.35% Si, respectively, are increasingly prone to weld-metal attack with increasing Si content in both anodic dissolution and tank tests. This trend is also evident in a qualitative way in Fig. 3, 4 and 5 which clearly show greater attack of weld metal and less attack in the HAZ with increasing Si content.

Group 3 - Specimens 302T and 302U containing ~1.5% Mn and 0.40 and 0.23% Si show the same dependence on Si content as do the weldments in Group 2. In addition, a direct comparison between 302U (1.59% Mn; 0.23% Si) and 302Q (1.21% Mn, 0.24% Si) demonstrates the detrimental effect of high Mn in the weld metal.

Group 4 - In the work of Malik et al. (1), optimum compositions of Cu and Ni singly in the weld metal were established. Specimens AM24 and 302X were fabricated to correspond to those optimum compositions. It is clear that both weld metals provide excellent matches with the base plate. It therefore follows that Cu is approximately twice as effective as Ni in reducing weld-metal corrosion.

The corrosion characteristics of the SAW weld metals with Si contents in the range 0.13 to 0.46% are summarized in Fig. 10 using the average weld-metal loss determined in the anodic dissolution test as the criterion. A step in corrosion rate at approximately 0.20% Si (for weld metal containing 1.5% Mn) and at approximately 0.25% Si (for weld metal containing 1.2% Mn) has been drawn because such response is the inverse of the effect of Si content in the baseplate noted by Rasanen and Relander (4). A curve with shape similar to Fig. 10 is also obtained if the maximum depth of attack in the weld metal determined in the tank test is used as the criterion.

The tendency toward enhanced HAZ attack at the last pass relative to the first is common to all of these multipass weldments and is obvious in Fig. 1-4 and 7-9. Low temperature transformation products which are responsible for enhanced corrosion in the HAZ formed by the first pass are tempered and consequently modified by the thermal transients resulting from subsequent passes. No such thermal transient occurs in the case of the last pass to modify the microstructure. It is clear that the low temperature transformation products responsible for enhanced attack are highly unstable since the modest degree of heat treatment associated with subsequent passes is sufficient to cause a significant reduction in HAZ corrosion.

CONCLUSIONS

The detrimental effect of Si content in the weld metal in both SMAW and SAW deposits has been documented. In the case of SAWs, a step function has been inferred with the location of the step dependent on Mn content. Whereas increasing Si and Mn lower corrosion resistance, Cu and Ni have been shown to increase resistance of weld metals. In high Si SMAW metal, the addition of 1.3% Mn (302X) or 0.7% Cu (AM24) provides an excellent match with the baseplate but is less corrosion resistant than the combination of 0.6% Ni and 0.5% Cu (302N).

It is clear that the corrosion resistance of both SMAW and SAW deposits can be controlled by the proper choice of Cu, Ni, Si and Mn levels.

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1. L. Malik, V.S. Donepudi, C. Chiu and G. Gaudreau "Study of the Effect of Weld Metal Composition on its Seawater Corrosion Resistance and CVN Toughness"; Fleet Technology Limited, Report TP #9416E; October 1988.

2. R. Brigham, M. McLean, V.S. Donepudi, S. Santyr, L. Malik and A. Garner "Evaluation of Weld-Zone Corrosion of Shipbuilding Steel Plates for Use in the Arctic Environment"; Can. Met. Quart. 27:311; 1988.

3. L.D. Parkinson, L. Malik, V. Mitrovic-Scepanovic and R.J. Brigham "Evaluation of Shielded Metal Arc Welding Consumables for Repair of Weld-Zone Corrosion"; Can. Met. Quart. 28:135; 1989.

4. E. Rasanen and K. Relander "Development of Shipbuilding Steel Plates for Use in Arctic Seas"; Scand. J. Metall. 7:11; 1978.

Table 1. Chemical analyses of weld metals and baseplate (wt %).

Specimen	C	Mn	S	P	Si	Ni	Cu	Ti	B
302M	0.05	0.74	0.015	0.010	0.13	0.62	0.56	0.005	0.0000
302N	0.05	0.81	0.014	0.011	0.38	0.60	0.54	0.006	0.0000
302P	0.07	1.17	0.016	0.016	0.13	0.07	0.09	NA	NA
302Q	0.07	1.21	0.015	0.015	0.24	0.06	0.08	NA	NA
302S	0.07	1.22	0.016	0.016	0.35	0.07	0.09	NA	NA
302T	0.07	1.48	0.008	0.013	0.46	0.02	0.08	NA	NA
302U	0.105	1.59	0.008	0.015	0.23	0.05	0.08	NA	NA
AM24(W)	0.05	1.35	0.011	0.009	0.28	0.03	0.68	0.005	0.0000
302X	0.05	1.30	0.013	0.012	0.49	1.29	0.02	0.065	0.0012
Base-plate	0.09	1.24	0.009	0.012	0.16	0.08	0.01	NA	NA

NA = Not analyzed

Table 2. Corrosion characteristics of weld metals.

	Anodic dissolution test		Tank test
Specimen	Average weld metal loss (μm)	Range of depth of attack (μm) (Av. of 3 traces)	Max. depth of attack(um)
302M	-73	-135/ 30	--
302N	-5	-75/125	635
302P	5	-120/200	--
302Q	63	-20/177	1070
302S	182	25/375	1780
302T	223	140/373	1600
302U	150	37/318	1650
AM24	128	23/310	1650
302X	76	-22/215	1270

Negative numbers indicate that the weld metal is standing proud relative to the base plate

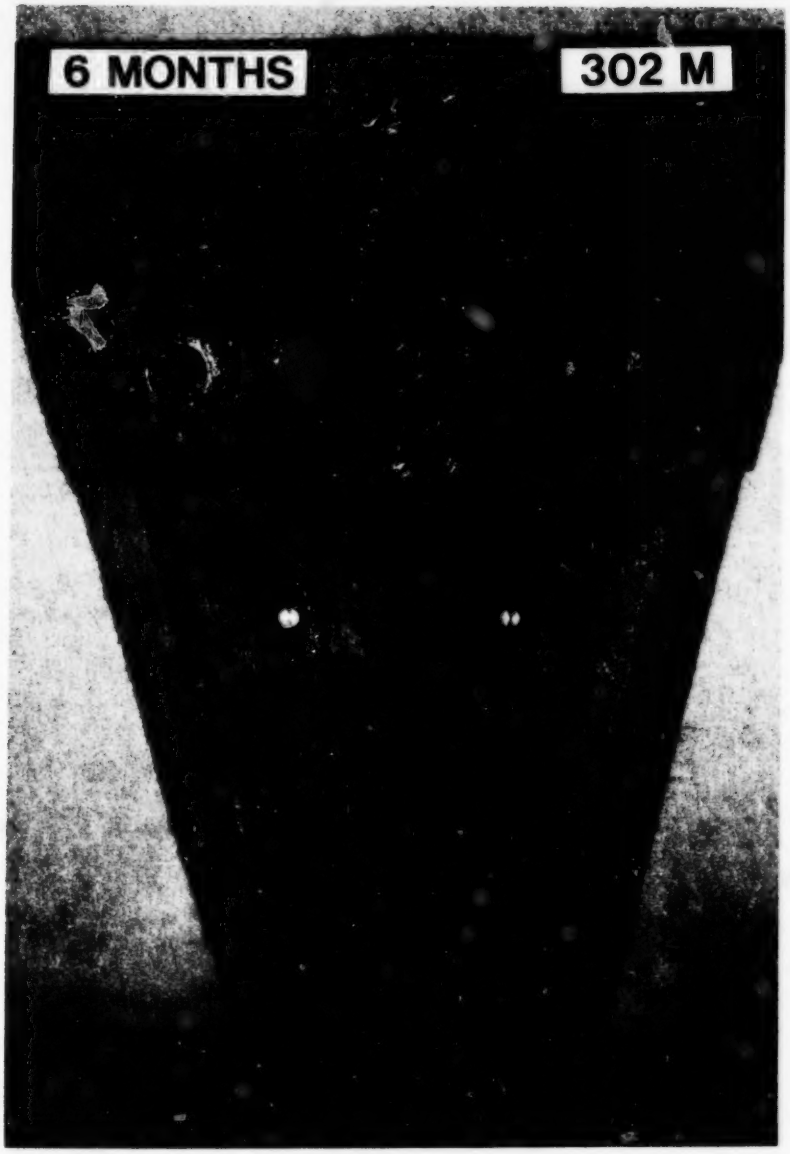

Fig. 1. Photograph of sample 302M after tank testing.

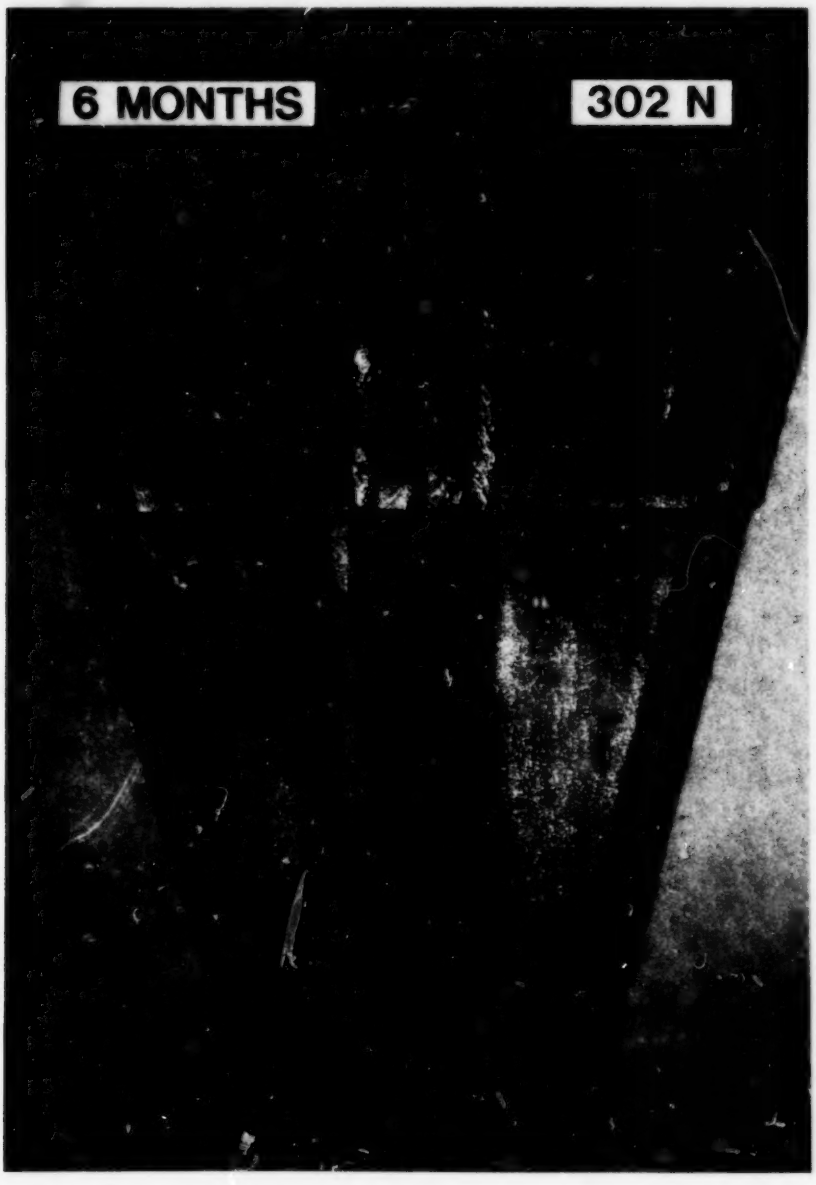

Fig. 2. Photograph of sample 302N after tank testing.

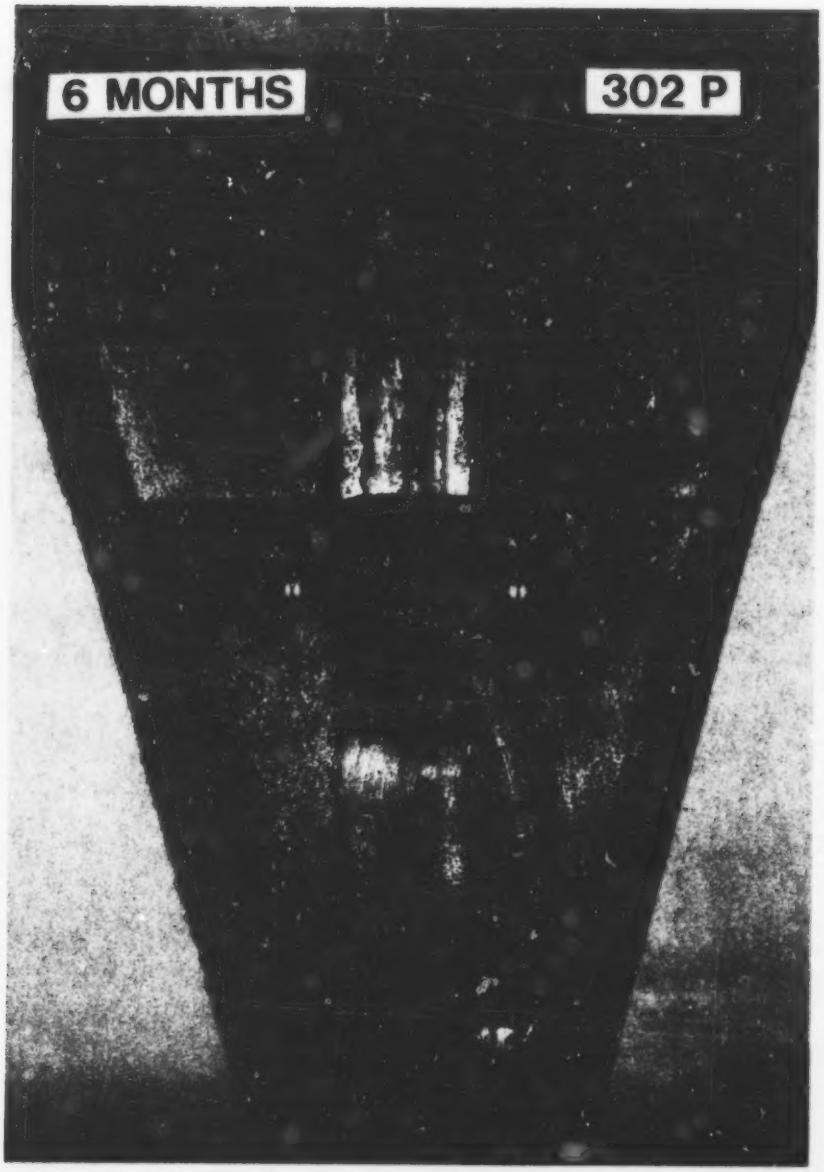

Fig. 3. Photograph of sample 302P after tank testing.

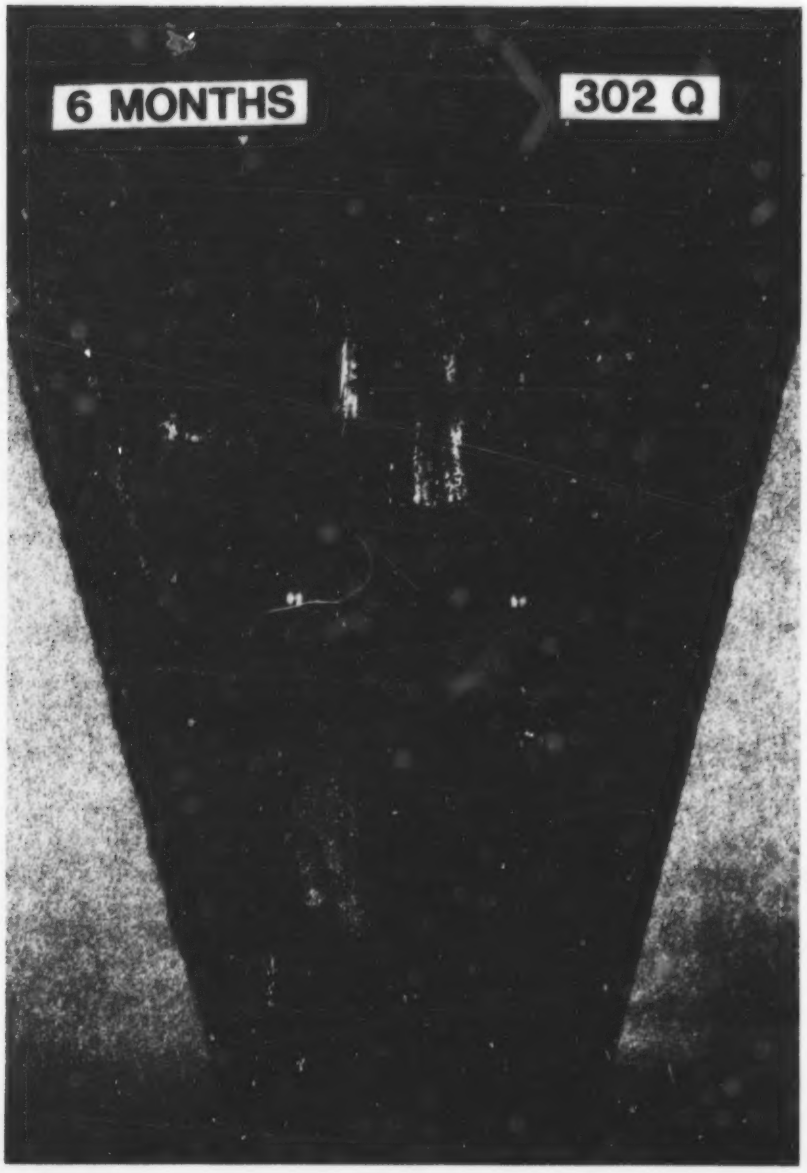

Fig. 4. Photograph of sample 302Q after tank testing.

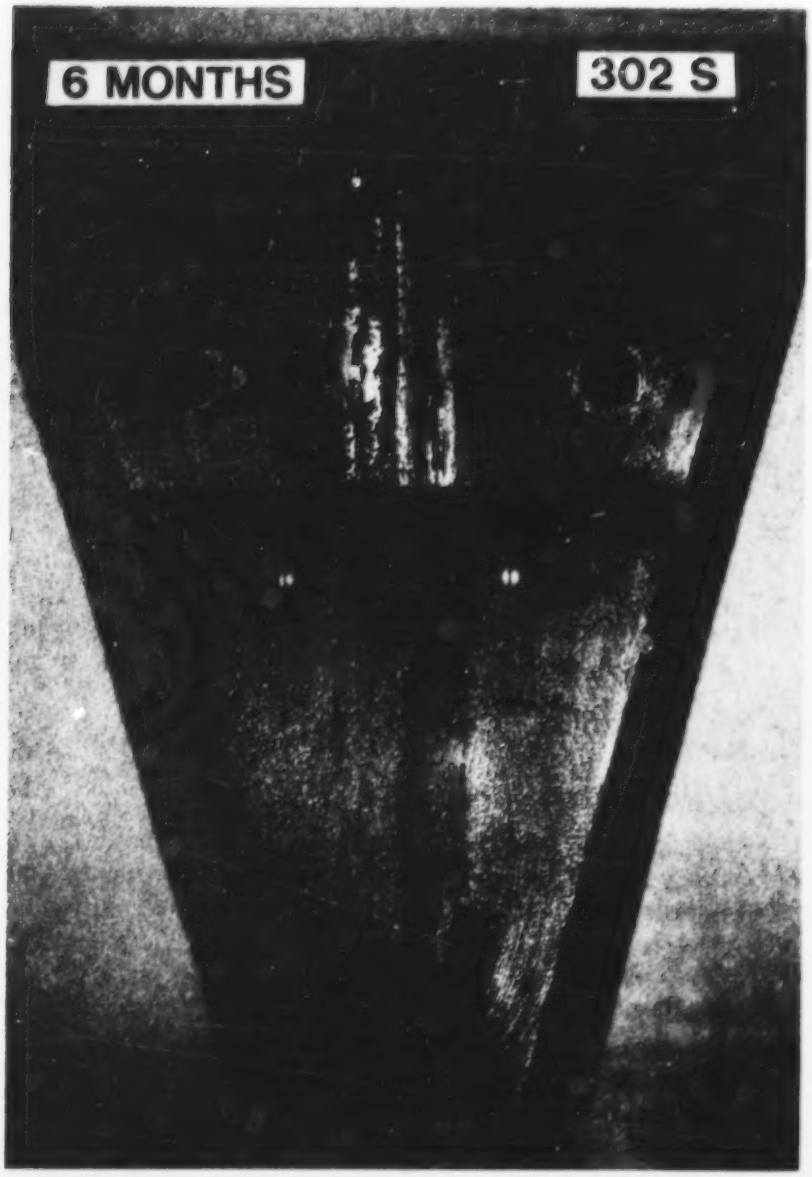

Fig. 5. Photograph of sample 302S after tank testing.

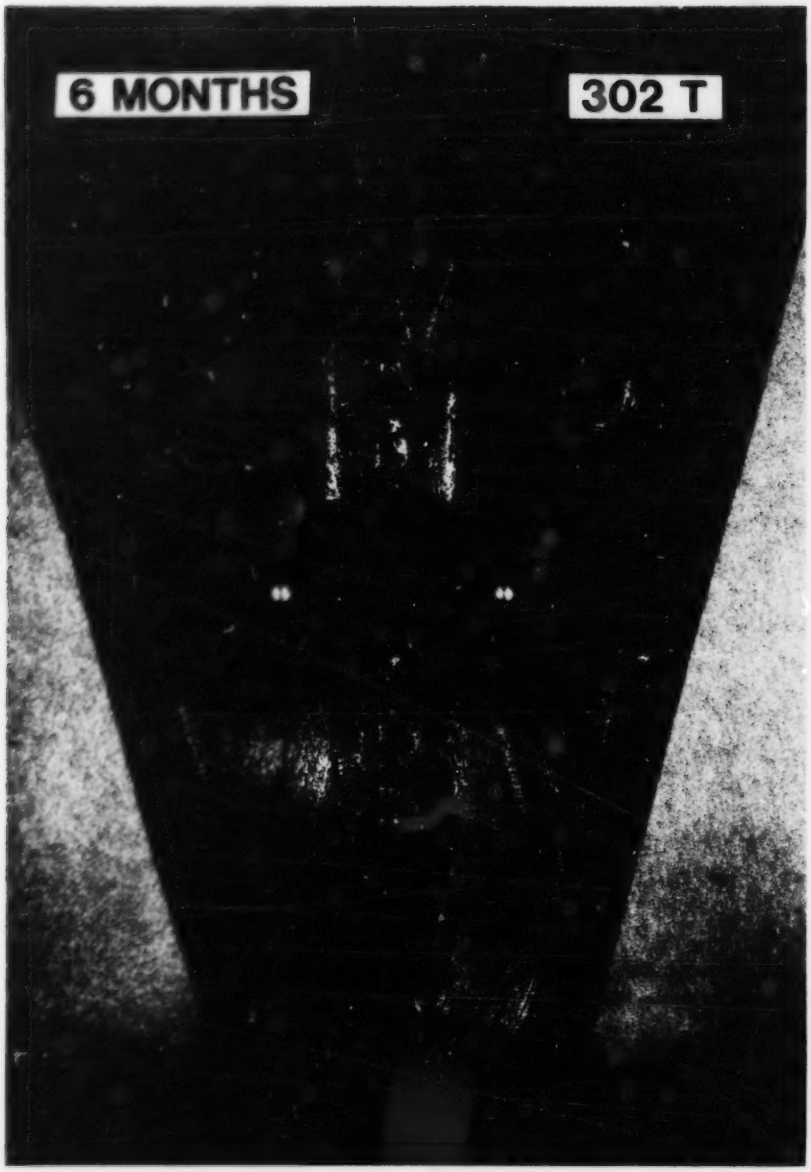

Fig. 6. Photograph of sample 302T after tank testing.

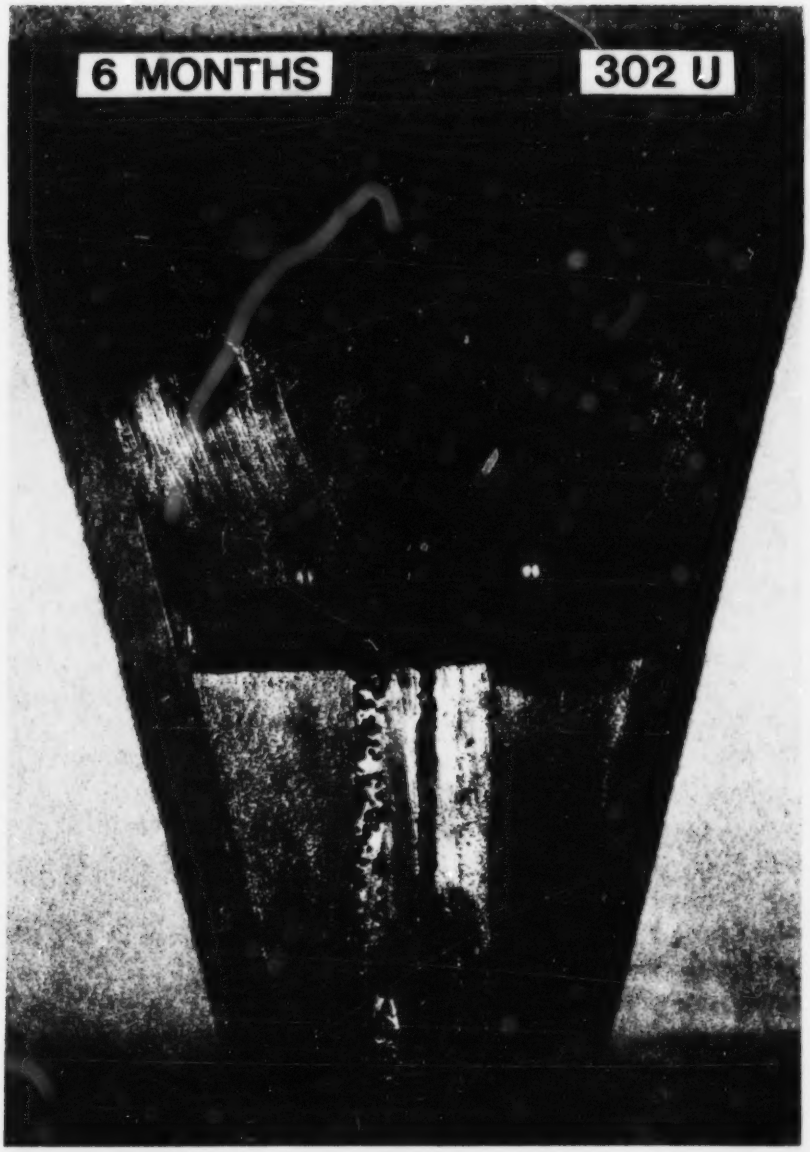

Fig. 7. Photograph of sample 302U after tank testing.

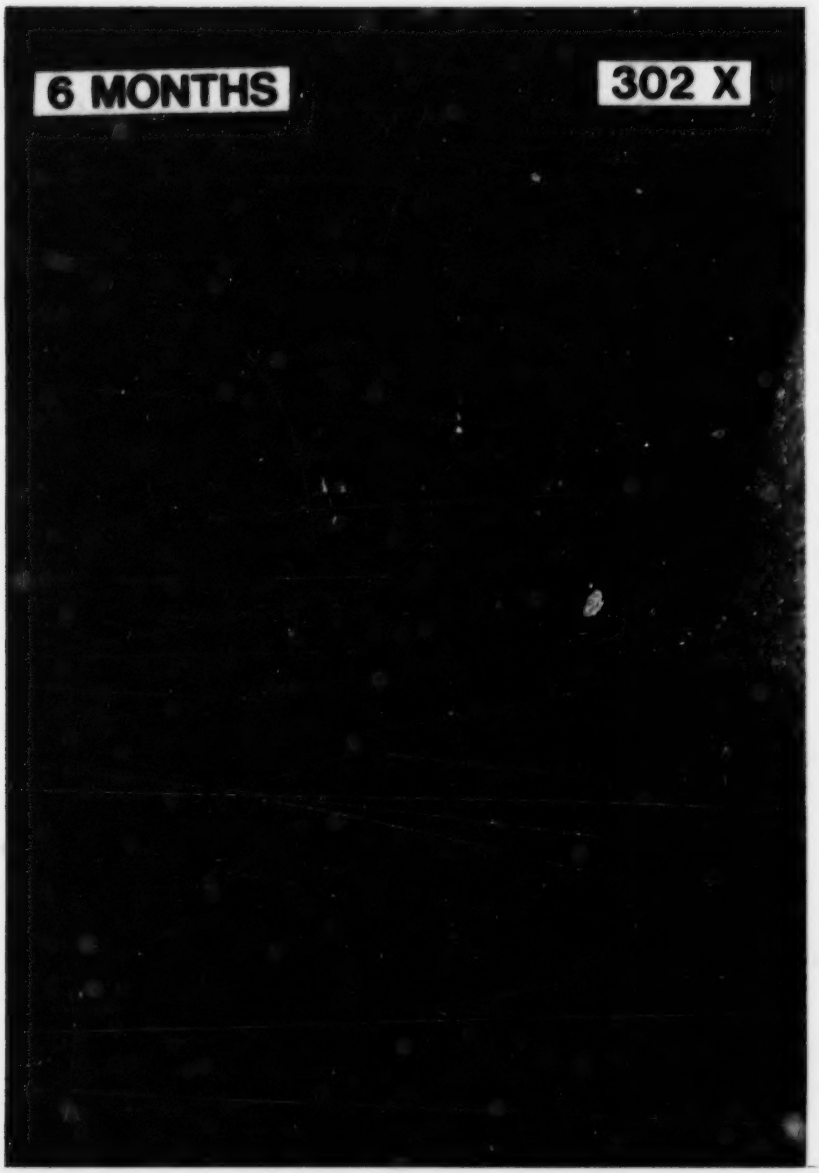

Fig. 8. Photograph of sample 302X after tank testing.

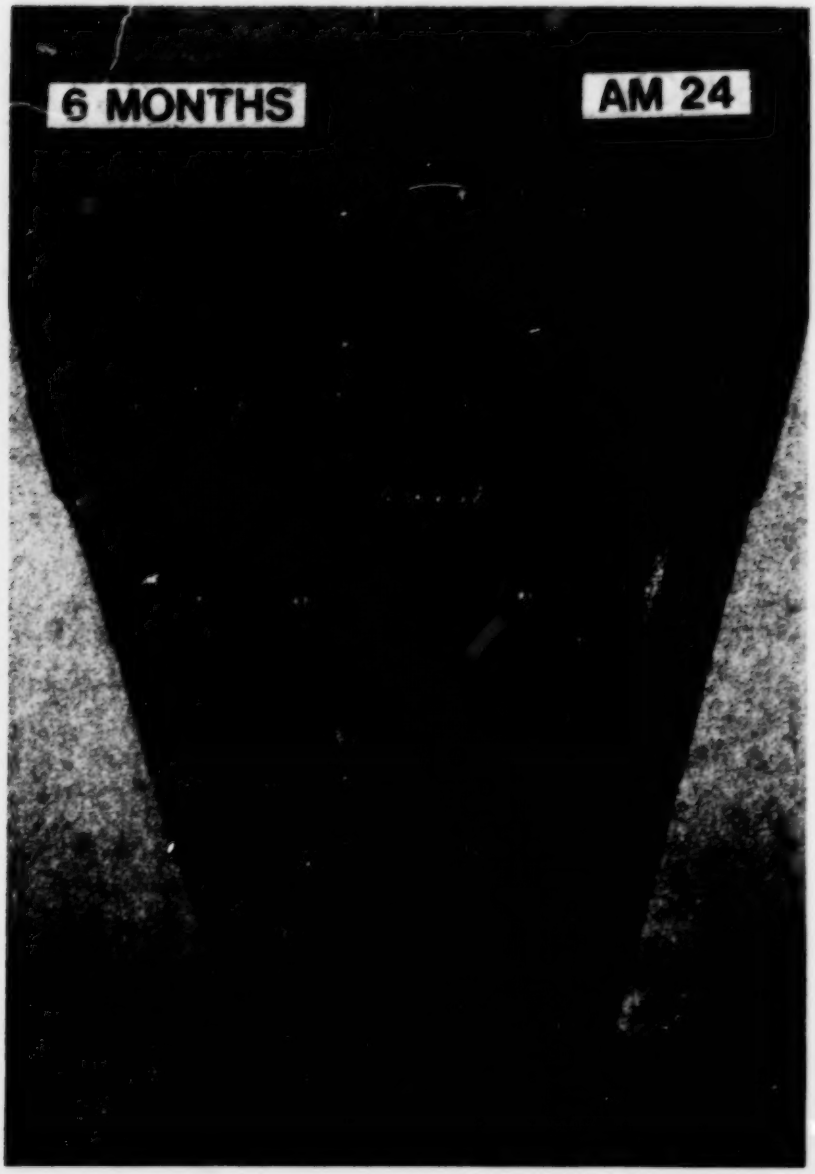

Fig. 9. Photograph of sample AM24 after tank testing.

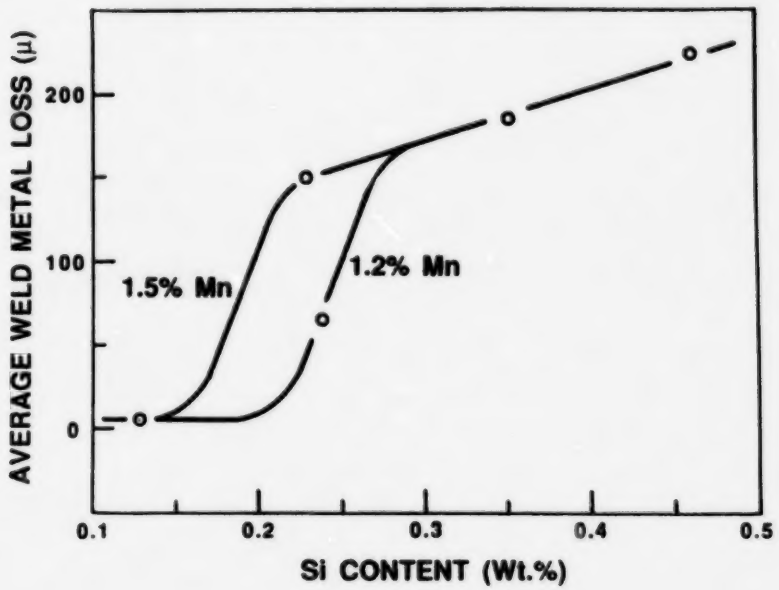

Fig.10. Corrosion rates of SAW weld metals as a function of Si content.
(neg 20010)